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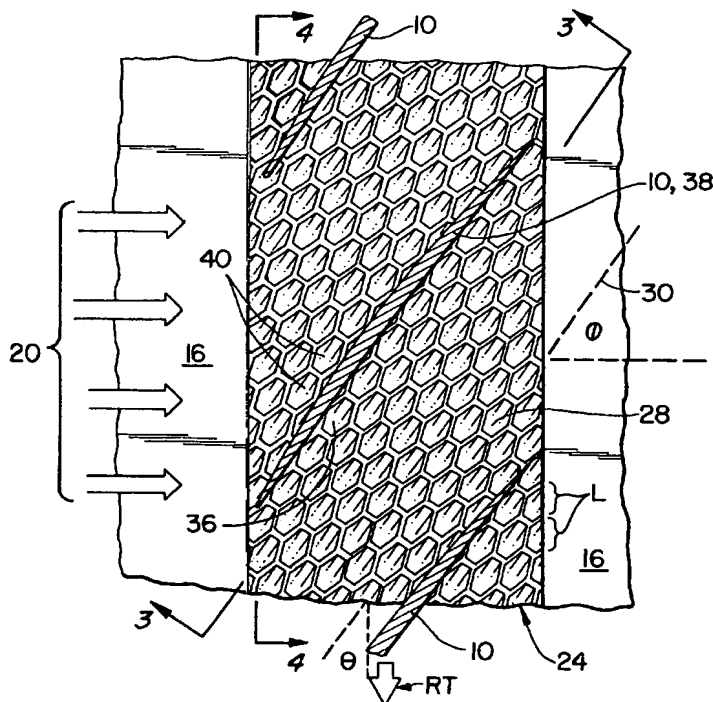
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(54) **Compressor shroud**

(57) The compressor section of a gas turbine engine contains a insert (24) installed around the compressor blades that includes cells (28) in a honeycomb configuration. Each cell is at a compound angle to the blade tip to energize the tip air flow as the tip passes over the cell as the blade rotates, improving the stall margin. Each

cell is oriented in the direction of the blade chord and facing the advancing blades. As the blade rotates it sweeps by each cell and high pressure airflow is first captured in the cell from the high pressure side of the blade and released to the low pressure side as the blade passes the cell, creating a energizing jet of high velocity flow in the direction of the airflow across the blade.



**FIG. 2**

## Description

This invention relates to gas turbines, in particular, techniques for improving compressor stall characteristics.

In a gas turbine engine, compressor blades are attached to a rotating disk with the blade tips as close as possible to the "endwall". Different sealing techniques are used to minimize the adverse effects of tip-endwall clearance and tip rub on the seal. Compressor rotor blade tip-endwall clearance growth significantly reduces compressor stall margin, mainly due to leakage between the pressure and suction sides of the blade. That leakage reduces total streamwise flow momentum through the blade passage, reducing blade pressure rise capability and therefore stall margin. A plot of pressure across the blade from root to tip would show a drop in total pressure towards the tip, due to that leakage. Stall margin loss from clearance increases perhaps arises from an interaction between the endwall and the blade suction side boundary layers, a condition that potentially could cause boundary layer flow separation on the suction side, causing flow blockage in that area.

An object of the present invention is to provide improved compressor stall margin by minimizing the adverse effect of tip clearance between the endwall and the compressor blade tips and by actively improving the flow characteristics near the blade tip.

Various features of the invention are set forth in the appended claims. According to one aspect of the present invention a special aerodynamic structure is placed between the blade tips and the endwall that "energizes" the tip flow in a way that enhances the streamwise momentum and produces efficient mixing of the endwall flows.

In a preferred embodiment, a shroud insert is placed in the endwall around the compressor blades that contains dead-ended honeycomb cells inclined at a compound angle. One angle component is relative to a tangential axis in the direction of blade rotation and the second angle component is relative to the radial (normal) orientation of the blades. As the blade pressure side advances, the honeycomb cells are "charged" with pressure side air and as the blade crosses each cell, the cell vents to the suction side, producing a transient jet of high velocity flow emanating from the cell that energizes the endwall flow.

The compound angle of the cell is selected to achieve two main objectives. The cell is oriented to face the advancing blade pressure side to capture the dynamic pressure imparted by the moving blade. This ensures that the cell is charged with air that is effective in producing an effective jet inducing pressure ratio. Also, the cell's orientation is preferably along the chord of the blade, so that that the resulting jet direction has a significant component in the streamwise direction, which enhances the streamwise flow momentum. The high velocity jets from the cells at this compound angle produce

efficient mixing of the outermost endwall flows (the stability impacting region) without disrupting the main flow, which minimizes efficiency losses. Components of the jets in the streamwise direction augment the streamwise momentum, a condition evidenced by the increased total pressure in the tip region.

The cell size is selected to result in a cell emptying time constant that is a fraction of the blade passing time period. The cell diameter (normal to the cell axis) is preferably in the order of the blade thickness, and the cell length of depth (along the cell axis) is preferably in the range of one to seven times.

A feature of embodiments of the invention is that it provides superior stall margin characteristics with minimal loss in compressor efficiency by energizing the flow field near the endwall (whether it is stationary or rotating). Another feature is that it can be used to improve the lift characteristics between an endwall and the tip of a lifting surface. For instance, in a compressor stator section, an insert with these cells can be placed on the rotating drum that faces the stator vane tips. A preferred embodiment of the invention will now be described by way of example only, with reference to the accompanying drawings, in which:

Fig. 1 is a sectional along line 1-1 of a typical gas turbine engine, shown in Fig. 8.

Fig. 2 is a plan view of section of a shroud surrounding the compressor blades of an engine according to the present invention.

Fig. 3 is a section along line 3-3 in Fig. 2.

Fig. 4 is a section along line 4-4 in Fig. 2.

Fig. 5 is an exploded view showing two layers of the shroud.

Fig. 6 is a perspective of several cells in the shroud.

Fig. 7 is an enlargement showing a blade tip and an adjacent layer of the shroud.

Fig. 8 shows a gas turbine engine in which the shroud is included.

In Fig. 1 a plurality of compressor turbine blades 10 are attached to respective compressor disks 14 with a case 16. The blades and disks are part of typical compressor section in a gas turbine engine, shown in Fig. 8. Stator vanes 18 are located upstream of the blades 10 to direct airflow 20. A circumferential seat 22 is provided in the case 16 to receive a ring insert 24 comprising layers of honeycomb cells 28, these being better shown in the enlarged view in Fig. 2. There, the arrow RT indicates the direction of blade rotation and the airflow to the compressor is again the arrow number 20. Fig. 1, shows that the insert 24 is constructed of layers L of the cells 28, and the cells, it will be noted, are oriented at a compound angle: one angle  $\theta$ , a second angle  $\phi$ . The angle  $\theta$  defines the displacement of the cell axis 30 from the blade tangential direction, RT in Fig. 2. The angle  $\phi$  defines the displacement of the cell axis from the normal (radial direction) 29 as shown in Fig. 3. It is perhaps easier to see in Fig. 3 that the cell axis 30 is oriented such that cell opening faces the advancing

blade, moving in direction RT. The cells are also on the chord line of the blades. The significance of these characteristics will be explained below.

As the blades rotate they sweep past the cells 28. This exposes the cells to different pressure conditions as a function of blade position. For example, refer to the one cell 36, and the blade 38 in Fig. 2, which shows the blade location at  $t_0$ . The cell is located at the high pressure side of the blade 36, but as the blade rotates in the direction RT it will be exposed to the low pressure side at a later time  $t_{+1}$ , as are the cells 40, which were pressurized at an early time (blade position)  $t_0$ . For clarity, it should be observed that arrow RTc in Fig. 3 indicates the component of blade velocity along the line 3-3 in Fig. 2.

Referring to Fig 7, the cell 40, pressurized initially at  $t_0$  from the high pressure side, as is the cell 36, provides a burst or jet of air 41 to the low pressure side of the blade after the blade passes over the cell. In addition to orientation of the cells relative to the blade or "air foil or lifting surface", the blade thickness should preferably be about  $d$ , the diameter of the cell and the depth or thickness of the cell  $L_1$  preferably at least equal to  $d$  and most preferably four times  $d$ . The ratio is important because it controls the time constant associated with the charging and discharging of the cell. The transient jets, with velocity components in the blade passage direction (due to the compound angle), produce energized flow at the blade tip, which causes efficient mixing, thereby preventing any potential flow separation in the endwall region.

The magnitude of the  $\theta$  and  $\phi$  depends on the specific compressor design, but essentially so that the cells are charged correctly and the outflow, energizing jet on the low pressure side is correctly oriented. Exemplary values for those angles are as follows:  $\theta=34$  degrees and  $\phi = 60$  degrees.

The invention significantly improves the stall margin of the compressor with minimum efficiency loss by efficiently energizing the endwall flow field. Tests of the design have also shown that the orientation of the cell angles is such as to make the insert a good abradable seal because the angled cells are shaved off easily without wearing the blade when a blade tip, having an abrasive tip (known in the art) rubs against the insert.

The flow energizing effect provided by the invention may be employed in the turbine section of a gas turbine engine by inserting a similar honeycomb insert around the turbine blades--but with an important difference in the cell pressurization as the turbine blade rotates. In the compressor embodiment described above, the cell is first exposed to the pressure side of the blade and then the lower pressure side. In a turbine, the cell is first exposed to the low pressure side, lowering the pressure in the cell and thereby inducing flow into the cell when the blade transits the cell. Leakage through the clearance between the turbine tip and the endwall is reduced by this, improving turbine efficiency.

With the benefit of the foregoing discussion and explanation, one of ordinary skill in the art may be able to modify, in whole or in part, a disclosed embodiment of the invention without departing from the scope of the invention.

## Claims

1. A gas turbine engine comprising a compressor stage having a case (16) and compressor blades (10), characterised by:
  - an insert (24) between the case (16) and tips of the compressor blades comprising means for capturing pressurized airflow from the high pressure side of blade tips to provide pressurized airflow in the direction of the airflow across the blade to the low pressure side of the blade as the blade rotates.
2. The gas turbine of claim 1, further characterised in that said means comprises a plurality of cells (28) in which each cell is oriented at an angle ( $\theta$ ) to the tangential direction (RT) in the direction of blade rotation to point downstream in the streamwise direction and at angle ( $\phi$ ) to a line (29) normal to the case.
3. The gas turbine engine of claim 1, further characterised in that said means comprises a plurality of cells (28) in which each cell extends towards the blade tip at an angle ( $\theta$ ) to a line (RT) tangential to the direction of blade rotation and at a second angle ( $\phi$ ) to a line normal to the case.
4. The gas turbine of claim 2 or 3 wherein the angle  $\phi$  is greater than  $30^\circ$ .
5. The gas turbine of claim 2, 3 or 4 wherein the angle  $\theta$  is greater than  $10^\circ$ .
6. The gas turbine engine of any of claims 2 to 5, further characterised in that said insert (24) comprises layers of honeycomb sheets each comprising said cells.
7. The gas turbine engine of any of claims 2 to 5, further characterised in that the cells (28) are polygons with a diameter that substantially equals the blade thickness ( $d$ ) and a depth ( $L_1$ ) that is no less than the diameter.
8. The gas turbine engine of claim 7, further characterised in that the depth ( $L_1$ ) is more than the diameter.
9. The gas turbine of any of claims 2 to 8 wherein said cells are oriented in the direction of the blade chord.
10. A method for energizing the flow in the tip region of

an airfoil (10) facing an endwall (16), the airfoil having motion to the endwall, characterized by the steps:

installing an insert (24) between the endwall and tip, the insert comprising means for capturing pressurised airflow from the high pressure side of blade tips to provide pressurised airflow in the direction of the airflow across the blade to the low pressure side of the blade as the tip moves relative to the endwall.

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16. The combination of any of claims 13 to 15 wherein said airfoil is a compressor blade or stator vane, or a turbine blade.

11. The method of claim 10, further characterised by:

the insert (24) comprising a plurality of cells (28) in which each cell extends towards the tip along the airfoil chord and at an angle ( $\theta$ ) that is greater than ten degrees from a line (RT) that is tangential to the direction of airfoil rotation.

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12. The method of claim 10 or 11, further characterised by:

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in that said insert (24) comprises a plurality of cells (28) in which each cell is oriented at an angle ( $\theta$ ) so that the cell axis has a component in the axial direction and at a second angle ( $\phi$ ) greater than thirty degrees to the normal to the endwall.

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13. The combination of an endwall (16) and an airfoil (10) having relative rotational movement to each other, characterised by:

an insert (24) between the endwall (16) and a tip of the airfoil (10), the insert comprising means for capturing pressurised airflow from the high pressure side of the tip to provide pressurised airflow in the direction of the airflow across the tip to the low pressure side of the blade as the airfoil moves relative to the endwall.

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14. The combination of an endwall (16) and an airfoil (10) having relative rotational movement to each other, characterised by:

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an insert (24) between the endwall and a tip of the airfoil, the insert comprising a plurality of cells (28), each cell being exposed to the high and low pressure sides of the airfoil as the airfoil rotates and lying at a compound angle to the direction (RT) of said rotational movement.

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15. The combination described in claim 14, further characterised by:

the insert (24) comprising a plurality of cells (28) in which each cell extends towards the tip along a line defining the chord of the airfoil and at angle ( $\theta$ ) greater than ten degrees to a line that is tangential to the direction (RT) of the relative motion of the airfoil, and the diameter of each cell substantially equals the tip thickness and the cell depth ( $L_1$ ) is at least equal to the diameter of the cell.

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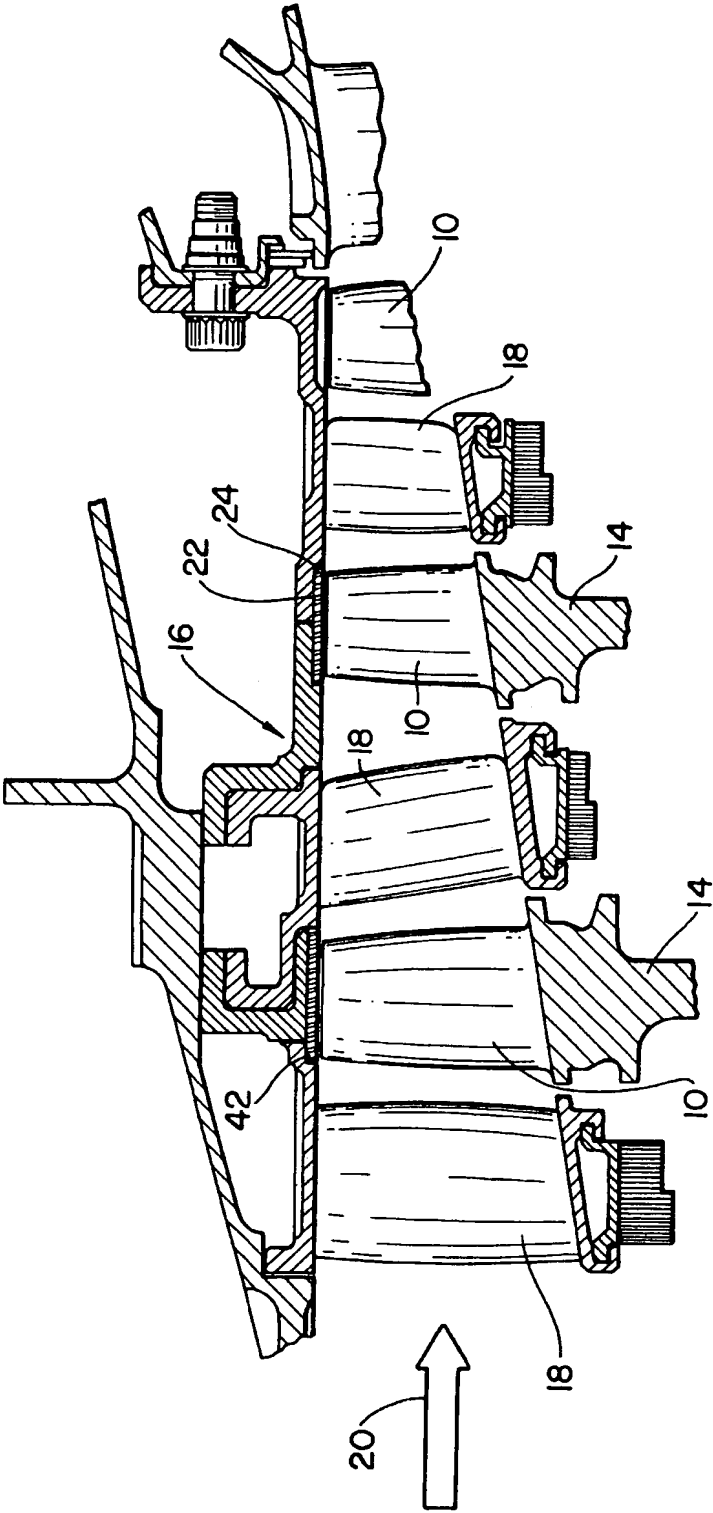


FIG. 1

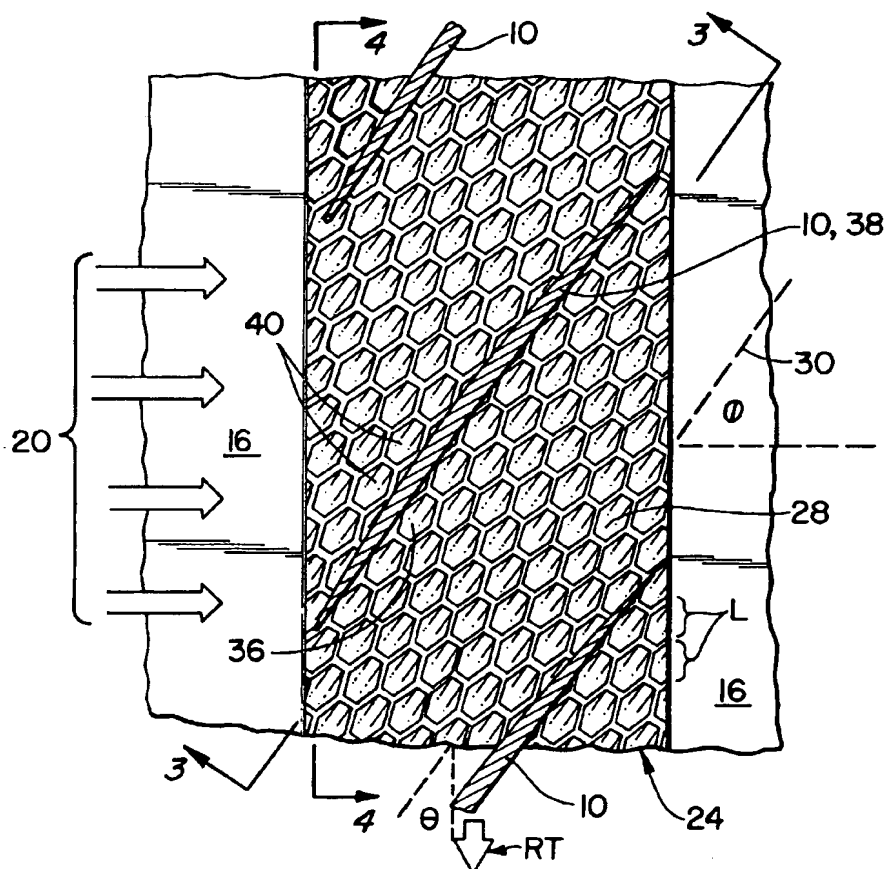


FIG. 2

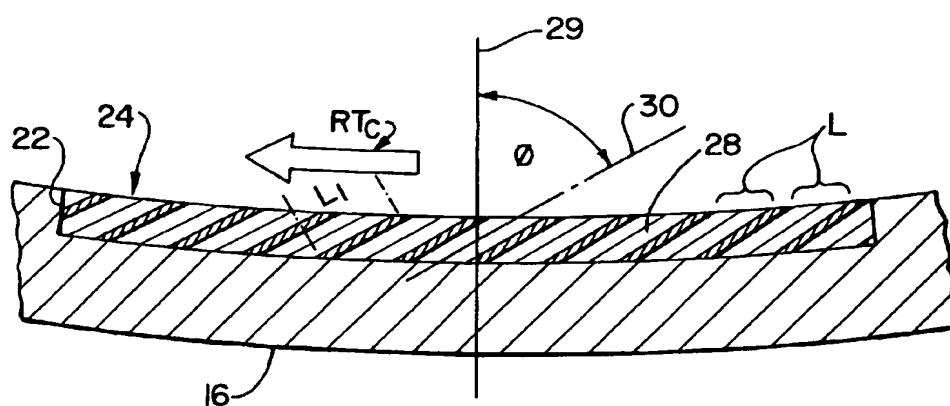


FIG. 3

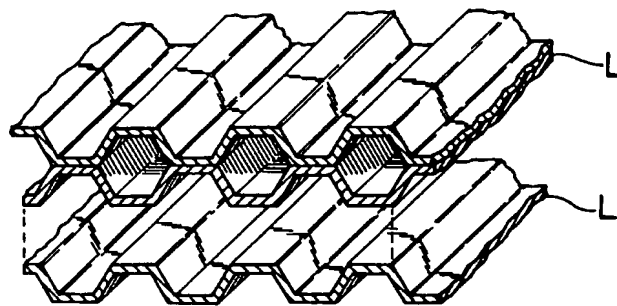
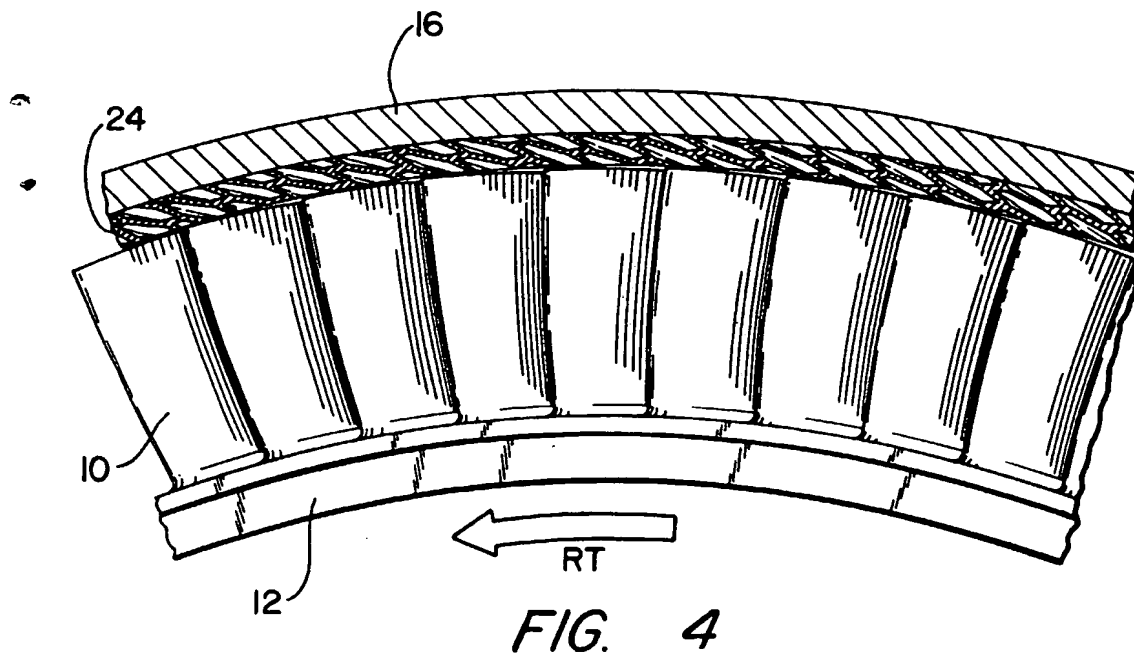


FIG. 5

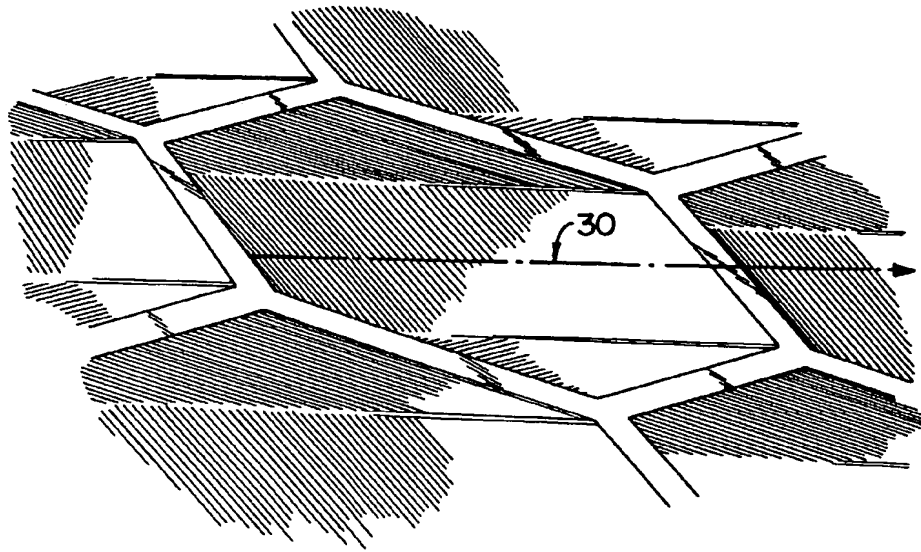


FIG. 6

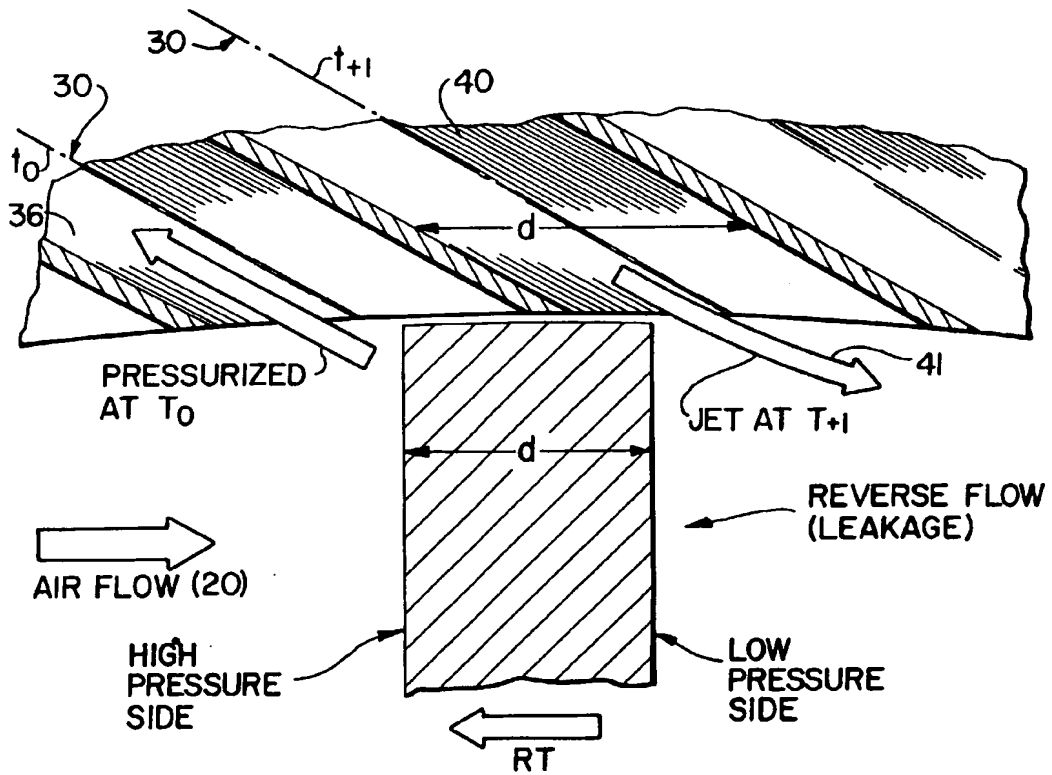
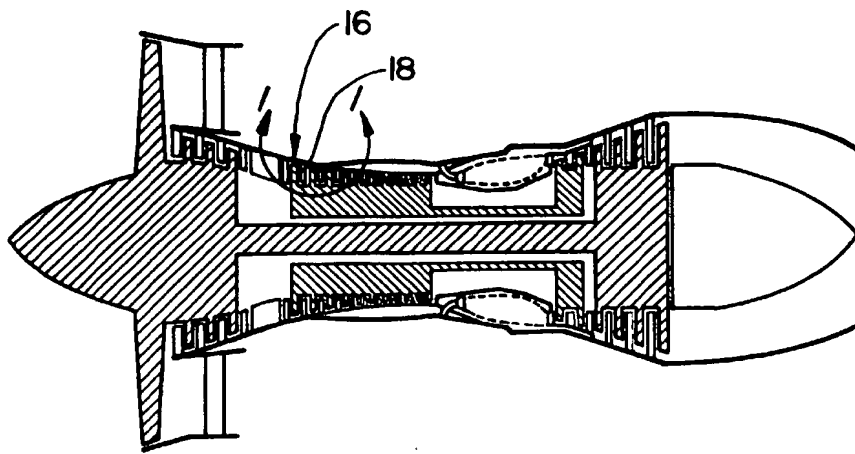


FIG. 7





*FIG. 8*



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## EUROPEAN SEARCH REPORT

Application Number  
EP 95 30 8806

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	DE-B-10 22 745 (MAN) 16 January 1958 * the whole document *	1-6,9-16	F01D11/08 F01D11/12 F04D27/02
Y	FR-A-2 325 830 (ROLLS ROYCE) 22 April 1977 * the whole document *	1-6,9-16	
A	DE-A-31 47 713 (MITSUBISHI HEAVY IND LTD) 24 June 1982 * page 5, line 8 - page 5, line 30 * * page 8, line 8 - page 8, line 19; figures 5,8-10 *	1-16	
A	EP-A-0 092 955 (KONGSBERG VAPENFAB AS) 2 November 1983 * the whole document *	1-16	
A	FR-A-2 551 130 (GEN ELECTRIC) 1 March 1985		
A	US-A-4 781 530 (LAUTERBACH JERRE F ET AL) 1 November 1988		
A	GB-A-2 017 228 (PRATT & WITNEY AIRCRAFT OF CAN) 3 October 1979		TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	GB-A-793 886 (SOLAR AIRCRAFT) 23 April 1958		F01D F04D
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 13 March 1996	Examiner Iverus, D
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